

On the effects of stenting on wall shear stress

Nicoud Franck¹, Vernhet Hélène²

¹University of Montpellier II – CNRS UMR5030

²University of Montpellier I – CNRS EA2992, France

Introduction

Angioplasty is a promising minimally invasive technique that can be used as treatment of occlusive disease in medium to large arteries. The use of intravascular stents tends to lower the complication rate, although restenosis rates as high as 15-30 % after 6 months for human coronary arteries have been observed. One possible explanation relies on the hemodynamic modifications induced by the prosthesis. Changes in wall shear stress (WSS) induce endothelial dysfunction (Caro et al., 1969), ultimately leading to intimal hyperplasia and restenosis. The objective of this study is to numerically assess the changes in WSS related to the compliance mismatch induced by stenting.

Methodology

The 2D pulsatile axisymmetric blood flow (Navier-Stokes) equations are solved over several cardiac cycles, the computational domain corresponding to a 80 mm long elastic vessel. When present, the endovascular stent is modelled as a rigid homogeneous 13 mm long prosthesis placed near the middle of the computed artery. The vessel impedance being zeroed at the rigid stent level, pressure wave reflection occurs due to the presence of the prosthesis. However, Nicoud et al. (2002) have shown analytically that the amount of reflexion is smaller than 1-2 % under the physical conditions considered. Thus one can assume that only forward propagating waves are present in the domain and the wall motion of the stented artery can be prescribed *a priori* under the linear elastic vessel assumption. As a consequence, it is not necessary to solve the full coupled fluid-structure problem; a simpler fluid problem with moving boundaries can be considered instead. Such numerical simulations are used in the present study in order to assess the changes in WSS induced by the geometrical perturbations related to stenting. The numerical method is finite element based and the Arbitrary Lagrangian Eulerian approach has been used in order to handle the prescribed geometrical changes over time (Nicoud et al., 2002). The input data for this study were obtained *via* animal experimentation (Vernhet et al., 2001). Using a surgical right femoral approach, self-expanding stents were placed in the infra-renal aorta of five New-Zealand white rabbits. With a fundamental frequency of 4 Hz (heart rate close to 240 bpm), mean diameter of 3 mm, the A'/A ratio was measured equal to $20.7 \times 10^{-6} \text{ Pa}^{-1}$ for the non-stented artery. Here A stands for the artery cross section area, $A_{\text{mean}} \sim 7.065 \text{ mm}^2$, and A' is the derivative of A with respect to pressure.

Results

Typical snapshots of the computed iso-lines of velocity are displayed in Figure 1. The geometrical mismatch due to the stenting is clearly visible, the prosthesis being located between $x=34$ and $x=47$ mm. A pulsatile Womersley profile is imposed at $x=0$ while the wall motion is prescribed by assuming hyperbolic tangent transition between the stented region and the elastic artery. Because of the compliance mismatch, the radius at the stent level is larger (smaller) than the radius of the proximal/distal artery during diastole (systole).

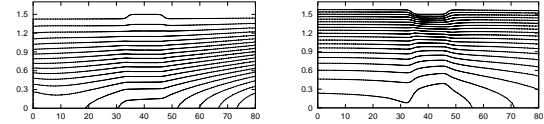


Figure 1 : Computed iso-lines of velocity in the stent region at diastole (left) and systole (right). Unit is mm.

Discussion and Conclusion

Table 1 reports the results obtained for different types of arteries and stenting. The variations in WSS during the cardiac cycle increase by 34% when the stent radius is equal to the mean radius of the elastic artery (1.5 mm). The increase is only 11 % when the stent radius is equal to the elastic artery at systole (overdilated stent). Note that these results correspond to the case where the fluctuating flow rate is two small to induce negative WSS during the cycle. Moreover, only the fundamental mode was used to generate the pulsatile flow and thus possible non-linear interactions between modes were not accounted for.

Artery/stenting	τ_{\min}	τ_{\max}	$\Delta\tau$	$\Delta\tau_{\text{scaled}}$
Rigid Artery	0,39	6,72	6,33	129 %
Elastic Artery	0,72	5,62	4,90	100 %
Stented Artery	0,42	6,98	6,56	134 %
Stented Artery with over-dilation	0,22	5,66	5,44	111 %

Table 1 : Variations in WSS at the stent location (Pa)

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Références

- Caro CG, Fitz-Gerald JM, Schroter RC (1969): Arterial wall shear and distribution of early atheroma in man. *Nature*, Sep 13;223(211):1159-60
- Nicoud F, Vernhet H, Dautat M (2002) Changes in Fluid Mechanics after Endovascular Stenting: the pressure wave point of view, *ESAIM Proceedings, EDP Sciences* (to appear).
- Nicoud F (2002) Hemodynamic changes induced by stenting in elastic arteries. *Center for Turbulence Research Briefs, Stanford University*, pp 336-347.
- Vernhet H, Demaria R, Oliva-Lauraire MC, Juan JM, Sénac JP, Dautat M (2001) Changes in wall mechanics after endovascular stenting in rabbit aorta: comparison of three different stent designs. *Am J Roent*, 176(3)803-807